RE-ORDER NO. 64-105

IONIZATION CHAMBER-GEIGER TUBE
INSTRUMENT FABRICATION PROGRAM

Prepared for

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California

Attention: Mr. C. J. Alpaugh

Contract No. 950658

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Prepared by

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FOREWORD

The Ionization Chamber-Geiger Tube Instrument Fabrication Program is described in this final summary report. This program was conducted for the Jet Propulsion Laboratory (JPL) by Electro-Optical Systems, Inc. under JPL Contract No. 950658. The 9.5-month program was initiated on 17 June 1963 and ended on 28 March 1964.

Acknowledgment is given to Dr. L. G. Despain, cognizant JPL engineer, for his technical and administrative assistance during this program.

ABSTRACT

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Three prototype and three flight ionization (ion) chamber-Geiger tube instruments were fabricated to JPL specifications during this program. All units, except the temperature control model, were subjected to vibration and thermal vacuum tests at the Jet Propulsion Laboratory. One prototype, Type Approval Model MC-1, was subjected to a more rigorous testing program that included the following tests: vibration, thermal vacuum, explosive atmosphere, humidity, rf interference, shock, and static acceleration.

The flight instruments will be carried on Mariner C spacecraft and will detect and measure the omnidirectional flux of corpuscular radiation in interplanetary space and near Mars. The energy detection thresholds are 0.5 Mev for electrons, 10 Mev for protons, and 40 Mev for alpha particles. The instrument assembly consists of ion chamber, Geiger-Mueller tube, and electronics subassemblies. The assembly weighs less than 2.6 pounds, and its dimensions are 13.4 by 9.8 by 5 inches. Power requirements are less than 500 milliwatts.

Although most of the instrument design was previously completed under other programs, several changes were made to the ion chamber subassembly. These changes included replacement of previously used header pins with Bendix Cerameterm pins, redesign of the collector mounting cup and spider, and modification of the header base to accommodate a removable filler tube for evacuating and filling the sphere with Argon. The method of mounting the ion chamber to the electronics chassis was modified to isolate the header pressure seal from stresses due to vibration.

Only minor design and fabrication problems arose during the program and these were resolved without major changes to the delivery schedule and program cost. These problems included header pin leakage, sphere weld joint leakage, circuit board terminal crazing, and spider spring tension failure.

Several component design improvements for increasing the instrument's reliability and reducing its cost were developed during the program. These improvements affect the ion chamber header pins, shielding can, spider, and electrometer.

Author

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1. INTRODUCTION

The program for the design and fabrication of an ionization chamber-Geiger tube instrument (Fig. 1-1) is described in this report. The major goal of this program was to fabricate three flight instruments, to JPL specifications, that would operate continuously for at least 400 days in a space environment.

The instrument will be flown by the Jet Propulsion Laboratory (JPL) on Mariner C Spacecraft to Mars. The ionization chamber-Geiger tube instrument will detect and measure the average omnidirectional flux of corpuscular radiation in interplanetary space between the orbits of Earth and Mars and in the vicinity of Mars. This instrument will also measure the average specific ionization produced by these charged particles.

Brief descriptions of program background, organization, accomplishments, and recommendations for improving instrument reliability are presented in this section.

1.1 Instrument Description

The instrument consists of an ionization (ion) chamber, Geiger-Mueller (G-M) tube, data conditioning circuits, and power supply. The overall dimensions of this 2.6-pound assembly are 13.4 by 9.8 by 5 inches. Four printed circuit boards contain the data conditioning and power supply circuits. Operating power for the ion chamber, Geiger-Mueller tube, and electronics is about 0.5 watt.

The major functional characteristics of this instrument include omnidirectional sensitivity to gamma rays, protons, alpha particles, and electrons; a count rate accuracy of $\pm$ 0.5 percent for a given flux; and capability of detecting flux changes of 2 percent or

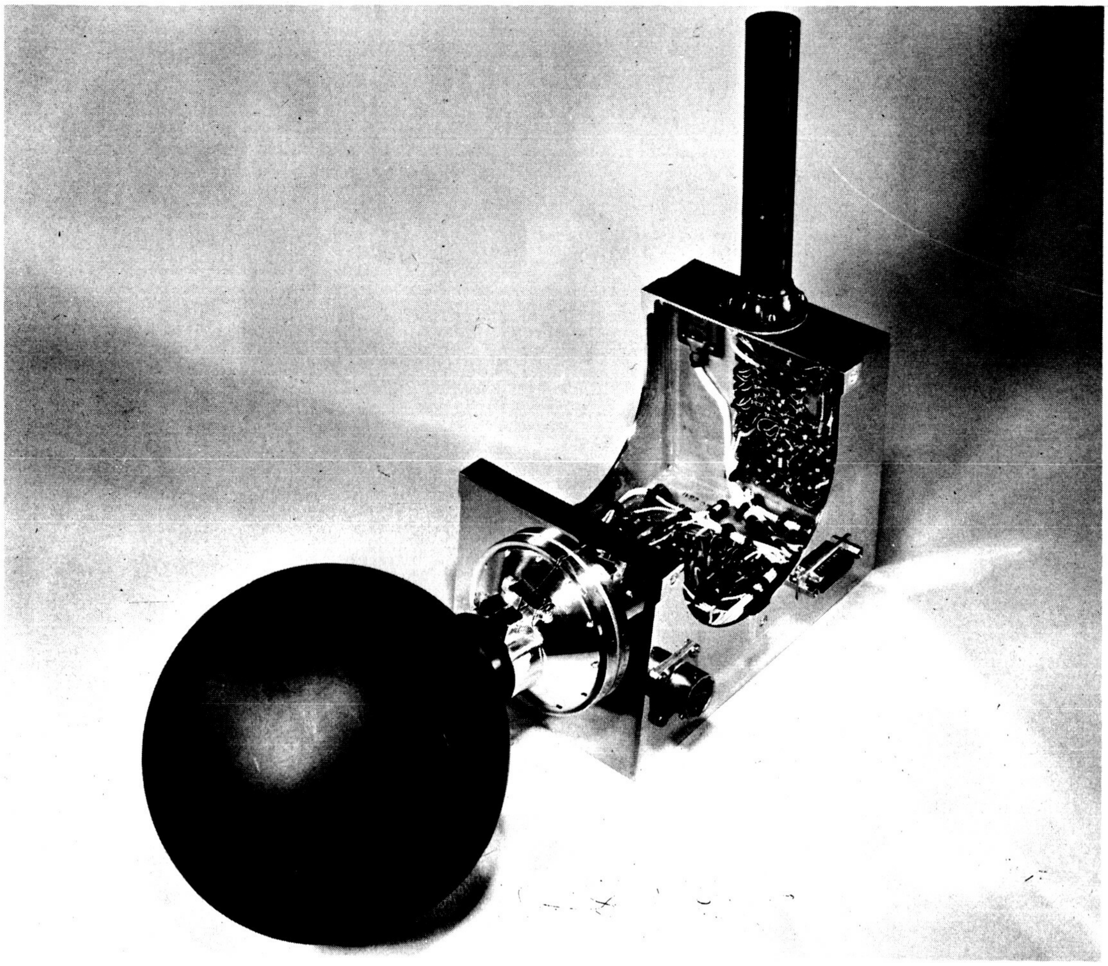

FIG. 1-1 IONIZATION CHAMBER - GEIGER-MUELLER TUBE INSTRUMENT

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greater. Depending on the flux, the output count rate is 0 to 100 pulses per second for the ion chamber and 0 to 50,000 pulses per second for the G-M tube.

1.2 Background

Ion chambers and Geiger-Mueller (G-M) tubes are radiation measuring instruments commonly used by JPL for spacecraft missions. Consequently, the basic design of these instruments was complete when Electro-Optical Systems, Inc. (EOS) was awarded a contract for building three prototype and three flight instruments.

The ion chamber was previously designed and developed by EOS for JPL under contract No. 950272. Five flight ion chambers were delivered to JPL on 26 October 1962. The G-M tube was designed and fabricated by Radiation Counters Laboratories, Inc.

1.3 Scope of Program

Although most of the ion chamber design was complete, a few minor changes were made to this subassembly during the program. Design changes included replacement of the header pins with Bendix Cerameterm pins, redesign of the collector mounting cup and spider components, and redesign of the header to accommodate a removable filler tube. In addition, a new method for mounting the ion chamber to the electronic chassis was developed to reduce the possibility of argon gas leakage from the header seal.

Although 90 percent of the fabrication work on this program was performed by EOS, the California Institute of Technology (CIT) coated the ion chamber collector and fiber before final assembly and testing of the instrument. Qualification testing of flight models was performed by JPL.

1.4 Program Organization

The organization of this fabrication program is shown in Fig. 1-2. The program was conducted by the Advanced Technology Department, and its performance was monitored by Dr. M. B. Prince,

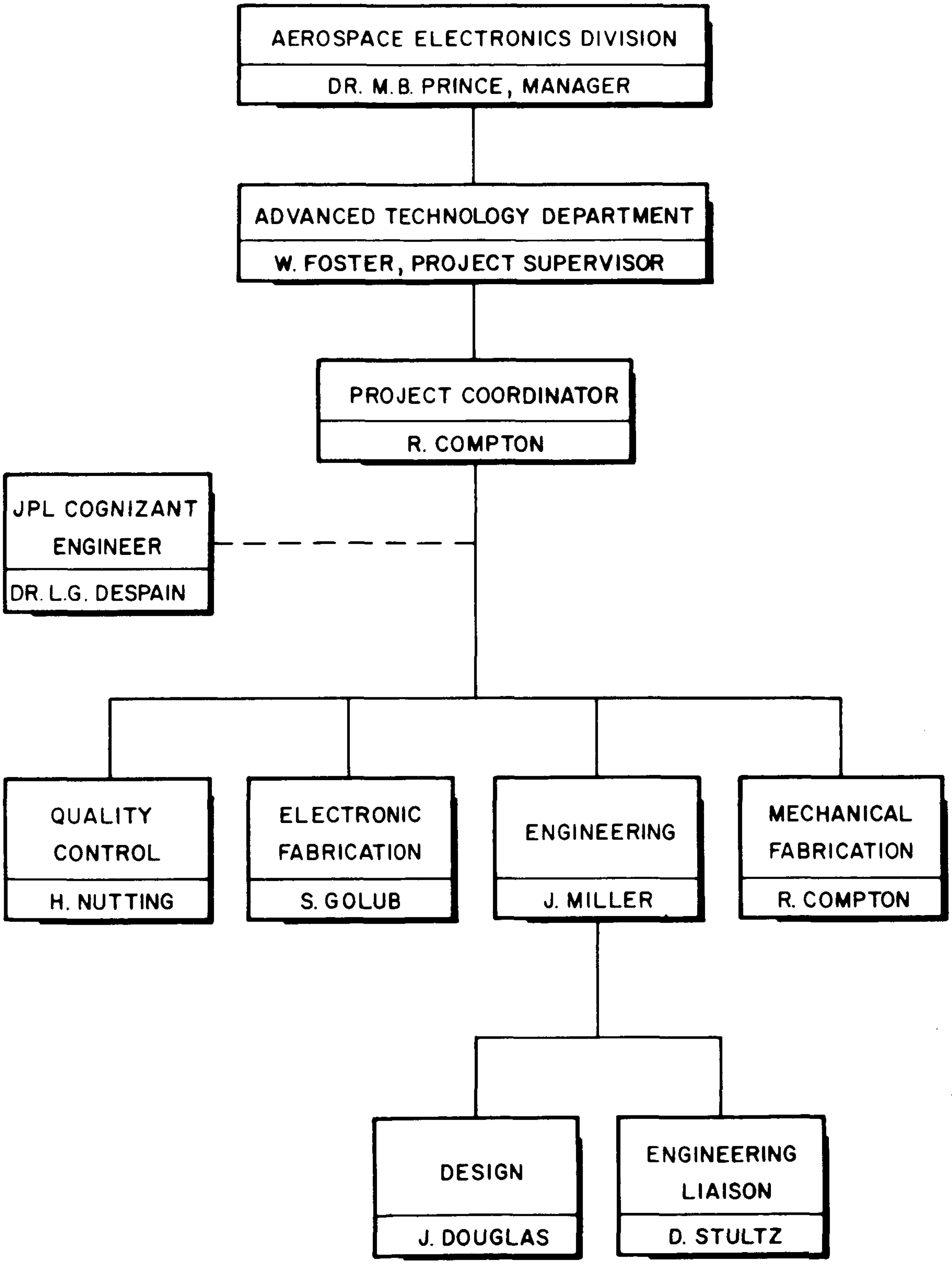

FIG. 1-2 PROJECT ORGANIZATION CHART

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Manager of the Aerospace Electronics Division. Dr. L. G. Despain, JPL Cognizant Engineer, monitored the program and worked closely with Mr. Foster, Project Supervisor, and Mr. Compton, Project Coordinator.

The fabrication program consisted of design changes, parts procurement and inspection, preparation of engineering drawings, mechanical fabrication, preparation of quality control procedures, and circuit board and instrument assembly. A JPL PERT Chart was used to schedule fabrication of all hardware.

1.5 Major Accomplishments

The major accomplishment of this program was the delivery of three prototype and three flight instruments to JPL. The prototype units consisted of type-approval, proof test, and temperature control models. These instruments met all requirements specified by JPL. A set of spare parts (except electronic components) for one flight model was also supplied. Other items delivered to JPL during this program included a quality control plan, detailed engineering drawings, a materials list, and monthly technical and financial reports.

Although several technical problems arose during the program, they were solved without long delays and large expenditures. Smooth coordination with JPL representatives was achieved without any major difficulties, and most problems requiring joint JPL-EOS agreements were resolved rapidly and amicably.

1.6 Recommendations

Several design improvements for the ion chamber subassembly were developed during this program. Incorporation of these improvements in future instruments will improve their reliability and reduce their fabrication costs. These recommendations are discussed in Section 5 and include the following ionization chamber components: header, shielding can, spider, and collector.

1.7 Scope of Report

The theory of instrument operation, and its physical and functional characterisitics, are discussed in Sections 2 and 3. Program requirements and procedures are summarized in Section 4. This section presents descriptions of JPL requirements, fabrication plans and techniques, quality assurance procedures, documentation, and problems encountered during the program. Conclusions and recommendations are given in Section 5.

2. SYSTEM DESCRIPTION

The purpose of the ion-chamber-Geiger tube instrument is to measure radiations in space during the Mariner C spacecraft voyage to Mars. The instrument consists of an ion chamber, Geiger-Mueller tube, data conditioning circuits, and power supply. Specific radiations measured include gamma rays, protons, and beta particles (electrons).

The ion chamber is the primary radiation measuring unit, and the Geiger-Mueller (G-M) tube provides supplementary data for interpreting the radiation spectrum. A block diagram of this instrument and its associated data conditioning circuits is shown in Fig. 2-1. A transducer provides temperature data for monitoring the thermal environment of the instrument electronics during the flight. A power supply, which includes an inverter, provides five voltage levels to the G-M tube, ion chamber, and electronics. The theory of operation for the ion chamber and G-M tube are presented below.

2.1 Ionization Chamber

The ionization chamber (Fig. 2-2) consists of a stainless steel sphere filled with argon gas. A quartz electrometer is housed within the sphere and consists of a quartz collector rod and a thin quartz fiber that is separated from it by 0.02 inch. (The collector is coated with Aquadag and the fiber is coated with a thin film of metal.) About 310 vdc are applied between the fiber and the sphere. The paragraphs given below describe the electrostatic states of the electrometer under two conditions: (1) absence of radiation; and (2) presence of radiation.

Although the collector is electrically isolated from the fiber and sphere, it normally has a positive charge. In the absence of ionizing radiations, this charge is produced by a 310 vdc

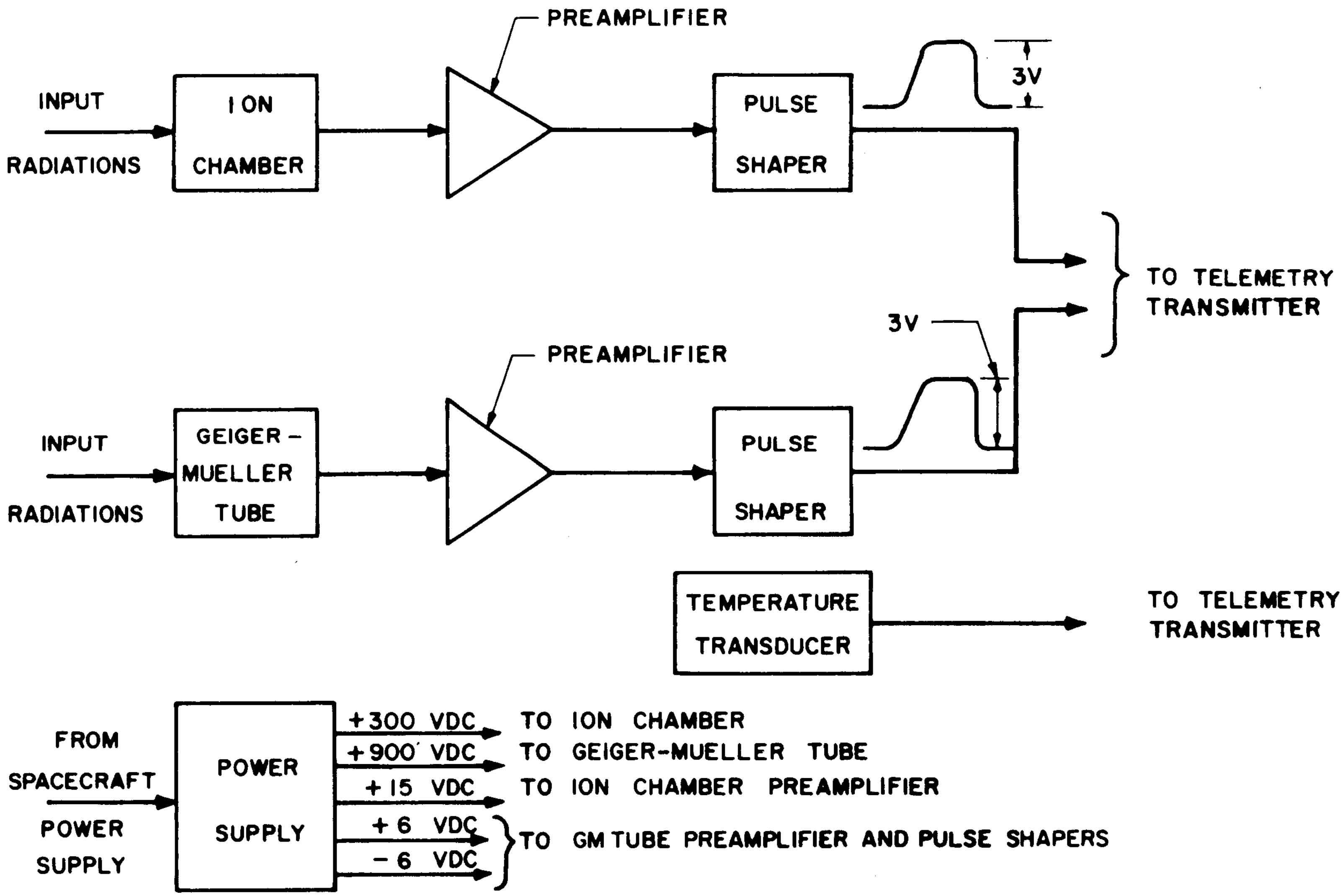

FIG. 2-1 ION CHAMBER-GEIGER TUBE INSTRUMENT, BLOCK DIAGRAM

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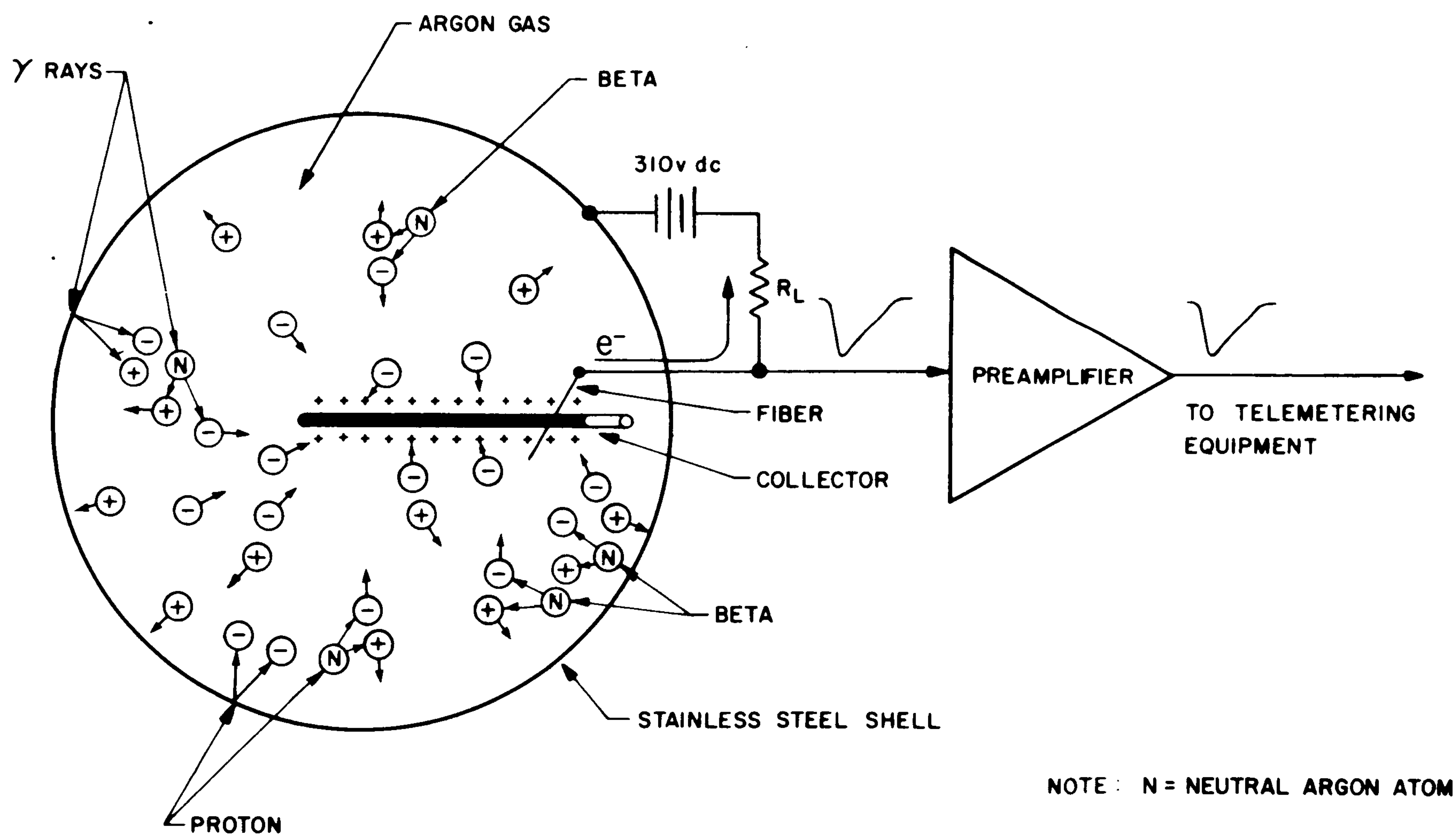

FIG. 2-2 ION CHAMBER RADIATION DETECTION

potential on the fiber, which induces an image charge on the Aquadag surface of the collector below it. As a result of this image charge, the fiber is attracted to the collector and momentarily contacts it. During contact, electrons pass from the collector to the fiber. When the collector potential equals 310 vdc, the fiber returns to its normal position.

When ionizing particles penetrate the sphere, and the gas within the chamber is ionized, the ions are attracted towards the negative potential sphere, and the electrons are attracted to the collector and tend to neutralize its positive charge. When the collector charge is sufficiently neutralized, the image charge, as previously described, attains sufficient magnitude and the fiber is pulled to the collector and contacts it. A surge of electrons passes from the collector to the fiber, and a pulse of current flows through R_L. This current pulse is amplified, shaped, and telemetered to a ground station. The current produced by the electrometer (not current from shaper) is proportional to the total energy loss by ionization of all radiations that penetrate the chamber wall and ionization due to secondary radiation produced within the walls and gas of the chamber. Each output pulse represents a fixed amount of charge collected from the gas. Thus, the interval between successive pulses is a measure of the radiation flux.

2.2 Geiger-Mueller Tube

The Geiger-Mueller tube consists of a shielded glass tube filled with neon gas. An insulated anode electrode passes through the tube and about 900 volts are applied between it and the cathode electrode which surrounds the inner side of the tube (see Fig. 2-3).

Ionizing particles penetrate the stainless steel shield and glass tube and ionize the gas molecules. The high electric field between the anode and cathode accelerates the dissociated ions and electrons. These charged particles gain kinetic energy due to their acceleration and ionize other gas molecules before they combine with

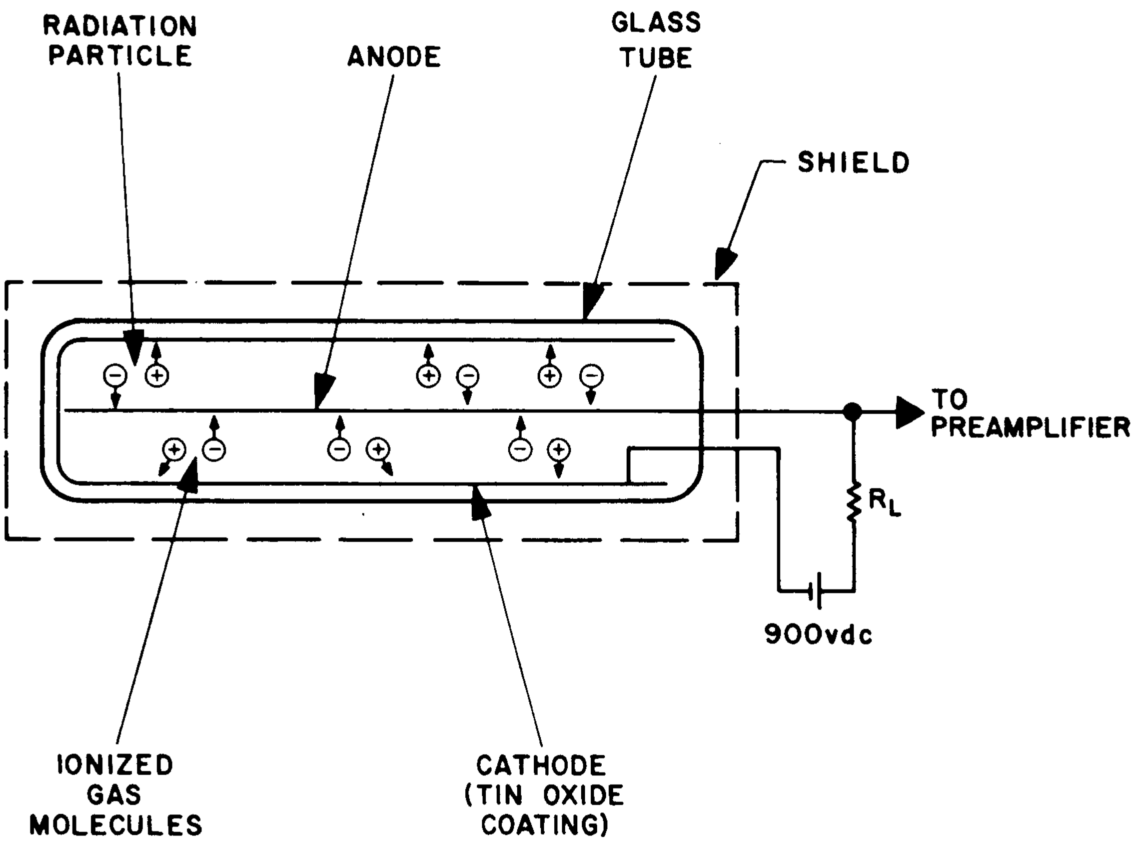

FIG. 2-3 GEIGER-MUELLER TUBE RADIATION DETECTION

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other charged particles to form neutral molecules or are captured by the anode. The newly created ions and electrons create additional charged particles, and the entire gas rapidly becomes ionized within a microsecond. These charged particles cause a current to flow between anode and cathode, and a negative pulse is developed across R_L. The pulse is then amplified, shaped, and telemetered to a ground station. One output pulse (constant amplitude) is generated for each charged particle that penetrates the shield and enters the sensitive volume of the G-M tube. Thus, the pulse rate is proportional to the radiation flux. Removal of the radiation causes the charged particles within the glass tube to re-combine and form neutral gas molecules, and the output signal is reduced to zero.

2.3 Radiations Measured

Gamma rays, electrons, protons, and alpha particles are measured by the ion chamber-Geiger tube instrument. Few gamma rays are detected by the instrument. Only very soft (low energy) gamma rays or x-rays are efficiently detected. Particle energy thresholds are 0.5 Mev for electrons, 10 Mev for protons, and 40 Mev for alpha particles. The ion chamber and Geiger-Mueller tube detect the same energy particles and both detectors have omnidirectional sensitivity. The ionization chamber measures the average rate of ionization, and the Geiger tube measures the average omnidirectional flux.

3. EQUIPMENT DESCRIPTION

The ionization chamber-Geiger tube instrument is a lightweight, compact radiation measuring device for spacecraft applications. An outline drawing of the instrument is shown in Fig. 3-1. The instrument weighs less than 2.6 pounds, and its overall dimensions are 13.4 by 9.8 by 5 inches. It consumes less than 500 milliwatts of operating power.

The instrument consists of three subassemblies: ionization (ion) chamber, electronics, and Geiger-Mueller tube. The ion chamber and G-M tube are bolted to the electronics and power supply subassembly at right angles to each other (see Fig. 1-1). The gold-plated electronic subassembly chassis contains a 2-inch radius cutout for mounting the instrument to a 4-inch diameter cylindrical structure on the spacecraft. The instrument is placed between two rings on the structure, and six screws (see cutout in Fig. 3-1) are used to attach the instrument to these rings.

Two connectors on the electronics subassembly provide connections for (1) input power to the instrument and (2) output signals to the spacecraft telemetry subsystem.

Descriptions of the ion chamber, G-M tube, and electronics subassemblies are discussed in Sections 3.1, 3.2, and 3.3. In addition, the instrument schematic and performance characteristics are given in Sections 3.4 and 3.5.

3.1 Ionization Chamber Subassembly

The ion chamber consists of a gas-filled 5-inch diameter sphere, an electrometer, a neck, and a support mechanism for securing the chamber to the electronics subassembly. The surface of the sphere and neck are black oxide, and the support surface is polished

NOTE: ALL DIMENSIONS IN INCHES

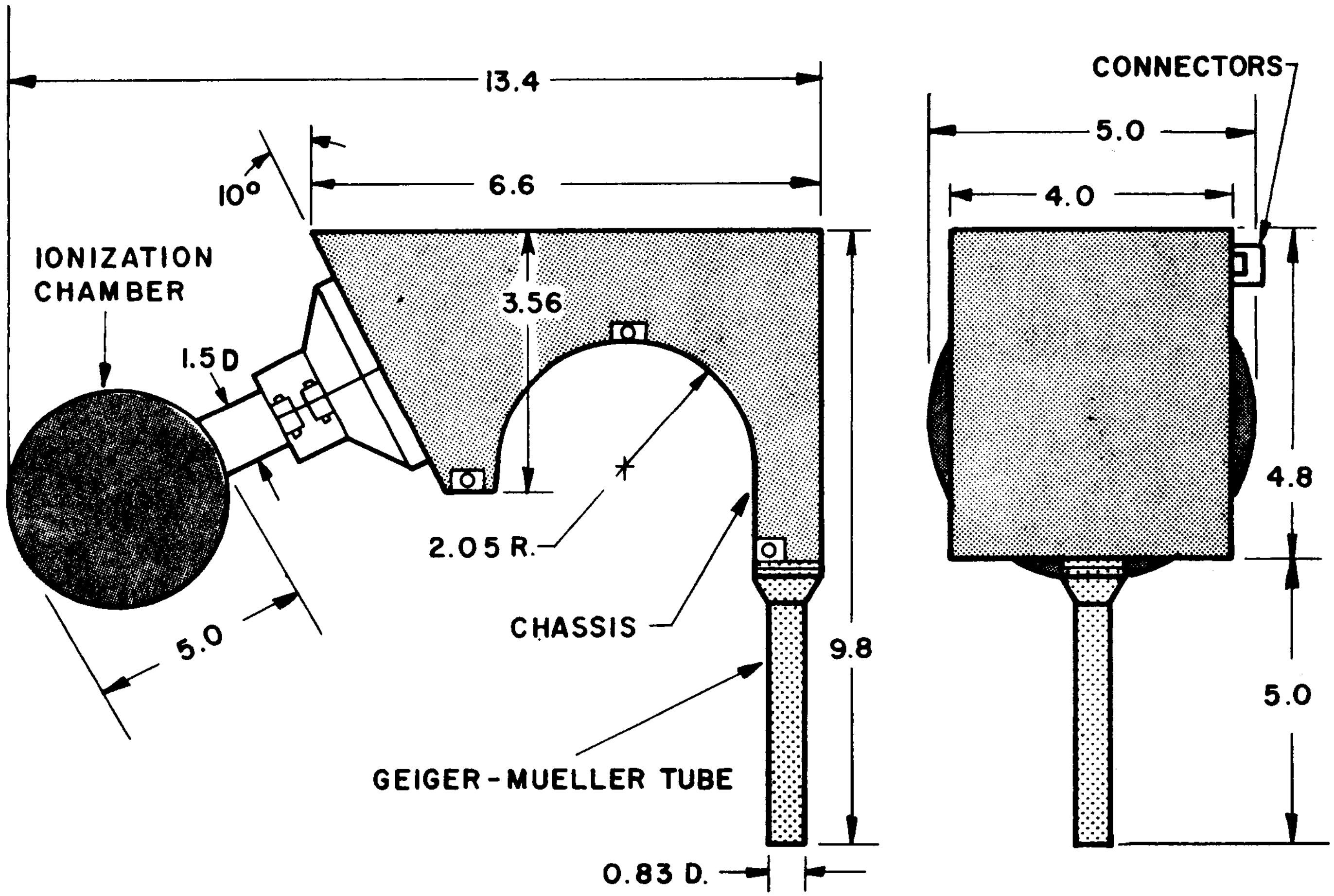

FIG. 3-1 OUTLINE DRAWING OF ION CHAMBER-GEIGER TUBE INSTRUMENT

aluminum. The overall length of the chamber subassembly is 7.3 inches, the neck is 1.5 inches in diameter, and the support base is 2.9 inches in diameter. It consumes less than 10 milliwatts of power.

The electrometer consists of a quartz ion collector rod, a quartz fiber, a shielding can, a spider, a spider spring, a cup, and a header. A cross-section of the ion chamber is shown in Fig. 3-2. The tapered quartz collector extends through the center of the sphere. The side arm, an integral part of the collector rod, supports the fiber that passes over the collector. The fiber is separated from the collector by 0.02 inch. The quartz fiber is welded to the side arm and coated with metal. An Aquadag coating is also placed on the side arm and collector; and the uncoated portion of the quartz collector is placed in a silver mounting cup that is held with a spring to a spider plate on the header. The spider is brazed to the header. The cup is then filled with molten silver chloride, which secures the collector rod to the mounting cup when it solidifies. To prevent variations in supply voltage from affecting the fiber, it is enclosed by a shielding can which reduces electrostatic forces between the fiber and sphere. This can is attached to the header by spot welding it to the spider skirt. One end of a platinum jumper wire is cemented to the side arm with silver chloride and the other end is welded to a header pin. The header seals the electrometer and argon-filled chamber interior from the atmosphere, and it provides electrical contact from the fiber to the preamplifier and high-voltage power supply (310 vdc). A filler tube is used to evacuate the chamber during assembly and to fill it with argon. It is threaded to facilitate removal for repeating the assembly procedure should the sphere develop a leak. A filter circuit, consisting of two resistors and a capacitor, is wired to the header pins (see Fig. 3-7).

The physical characteristics of the chamber are summarized in Table 3-I.

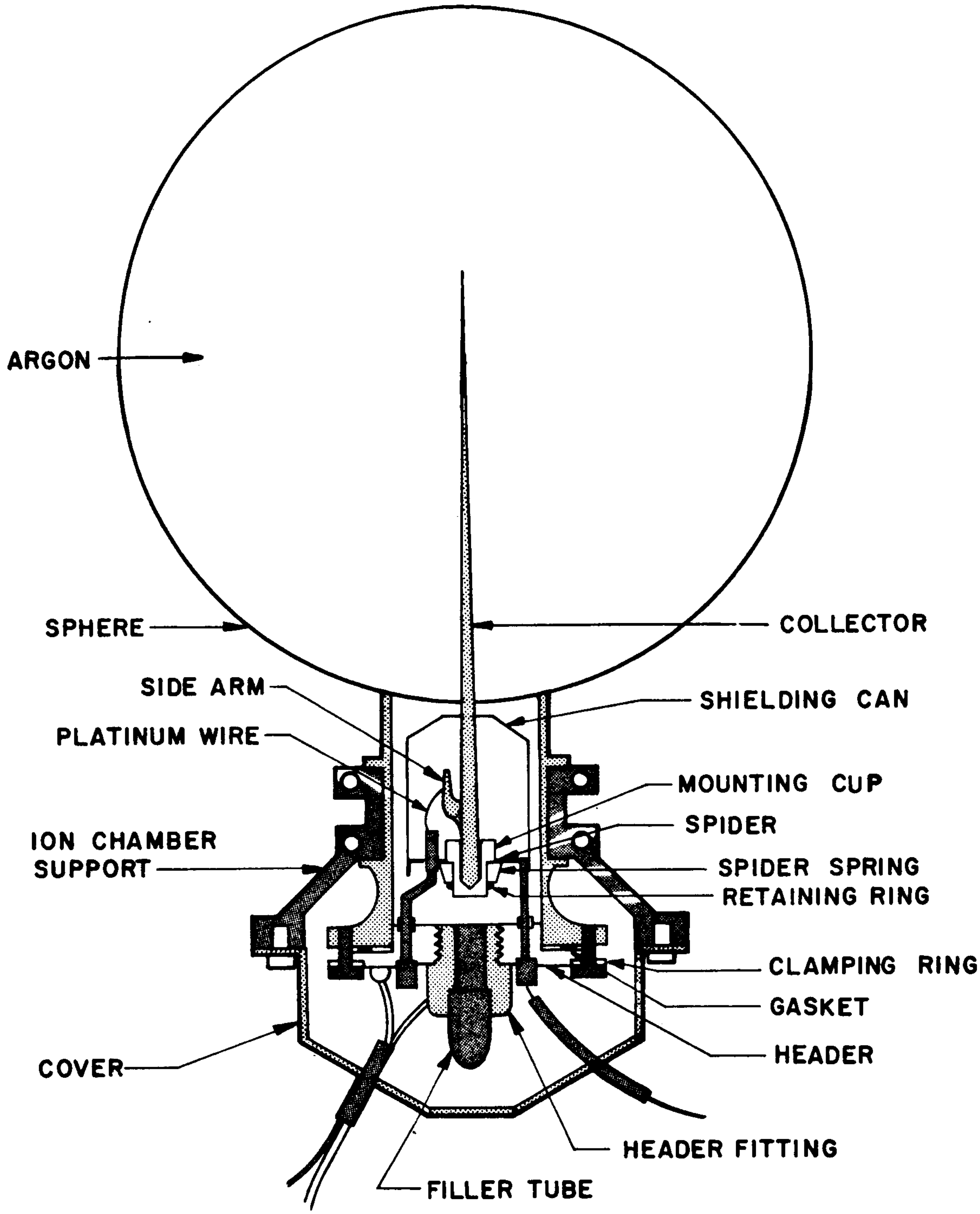

FIG. 3-2 CROSS SECTION OF ION CHAMBER

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TABLE 3-I

PHYSICAL CHARACTERISTICS OF ION CHAMBER

Characteristic	Description
Power Required	3 Microwatts
Voltage Source	310 vdc at 10^{-8} amperes, $\pm$ 3 percent regulation
Gas Fill	Argon
Operating Temperature	-55 to 70°C
Volume (Sphere)	66 Cubic Inches
Sphere Diameter	5 Inches
Sphere Material[a]	Stainless Steel
Sphere Thickness	0.010 Inch
Sphere Shielding	0.2 grams/cm^2
Sphere Pressure	60 $\pm$ 5 psia (4 atmospheres)
Weight	< 1 lb

[a]See Table 4-II for materials used to fabricate other components.

3.2 Geiger-Mueller Tube Subassembly

The Geiger-Mueller tube subassembly consists of a Model 10311 G-M tube and a stainless steel cylindrical shield. The G-M tube is manufactured by Radiation Counter Laboratories.

The Geiger tube (Fig. 3-3) is a thin-walled general purpose instrument filled with neon and halogen gases. A small amount of halogen gas is used to quickly restore (quench) the ionized neon atoms to their neutral state after the radiation is removed. The glass tube is 4.75 inches long and 0.62-inch in diameter. A .003-inch diameter tungsten anode extends across the tube and is supported on one end by a glass insulator. The cathode, a tin oxide coating around the inner surface of the glass tube, contacts a metal ring which connects to a short electrode.

The tube is shielded by a 0.83-inch diameter stainless steel cylinder that is 5 inches long. Two RTV insulators support the G-M tube at its ends. The 0.008-inch-thick cylinder is black oxidized and has four 0.125-inch diameter holes at its base for mounting to the electronics subassembly. An indium washer is used between the instrument and electronic subassemblies to improve thermal conduction. A threaded metallic sleeve covers the G-M tube shield and protects it during transportation and storage. The physical characteristics of the Geiger-Mueller tube are shown in Table 3-II.

NOTE: DIMENSIONS IN INCHES

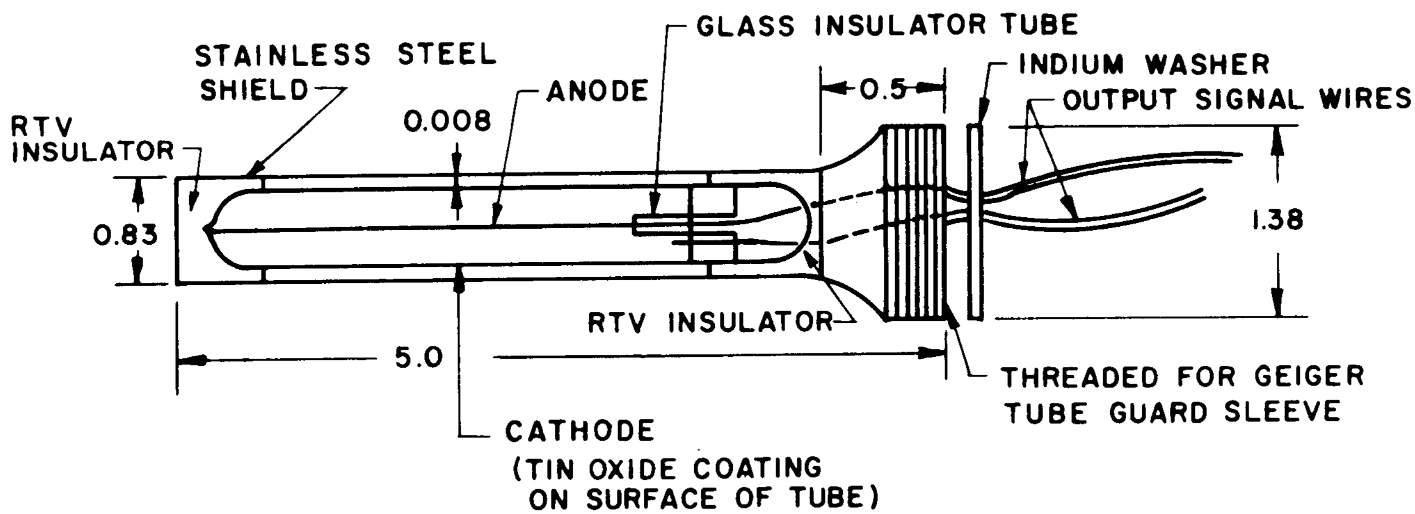

FIG. 3-3 CROSS SECTION OF GEIGER-MUELLER TUBE

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TABLE 3-II

PHYSICAL CHARACTERISTICS OF GEIGER-MUELLER TUBE

Characteristics	Description
Voltages:	
Operating	900
Starting	800
Plateau starting	850
Plateau length, Min.	150
Plateau slope, max percent per 100 V	2
Maximum safe voltage	not critical
Gas Fill:	
Type	Neon
Quench	Halogen
Operating temperature range	-55 to 75°C
Hysteresis and photosensitivity	None
Active anode length	3 inches
Wall thickness, Mg/cm^2	30
Tube O.D.	9/16 inch
Overall diameter	5/8 inch
Overall length, less pins	4.75 inches
Base Connectors	3 pins
Weight (without shield)	0.5 oz
Materials:	
Cathode	Tin oxide
Anode	3 mil tungsten
Wall	Glass

3.3 Electronics Subassembly

The electronics subassembly consists of data conditioning and power supply circuits that are fabricated on four printed-circuit boards.

All circuit components (transistors, capacitors, diodes, etc.) are mounted on one side of laminated-epoxy printed circuit boards and are soldered to spade lugs. Some components, such as transistors, transformers, and large resistors, are bonded to the circuit board with epoxy. A conformal coating of epoxy covers the components and circuit board and provides protection against moisture corrosion and electrical leakage. For identification, circuit board and drawing numbers are etched onto the surface of each board. An insulating board is bonded to the back of each circuit board and the boards are held to the subassembly chassis by screws and an epoxy bonding material.

The dimensions of each circuit board and the circuits mounted to it are given in Table 3-III. Circuit Board 1 is mounted to the right side of the chassis as shown in Fig. 1-1. Circuit boards 2, 3, and 4 are shown in Figures 3-4, 3-5, and 3-6.

TABLE 3-III

PHYSICAL CHARACTERISTICS OF
CIRCUIT BOARD ASSEMBLIES

Circuit Board	Dimensions (inches)	Circuits Contained on Each Board
TB1-J4801304B	3.2 by 2.1 by 1	G-M tube amplifier and pulse shaper
TB2-J4801306B	3.5 by 3 by 1	Ion chamber amplifier and pulse shaper
TB3-J4801308A	3.7 by 3.5 by 0.55	High and low voltage power supply, except T1
TB4-J4801310A	6 by 3.7 by 0.75	Full-wave bridge rectifiers (T2 and bottom winding of T1), converter and regulator

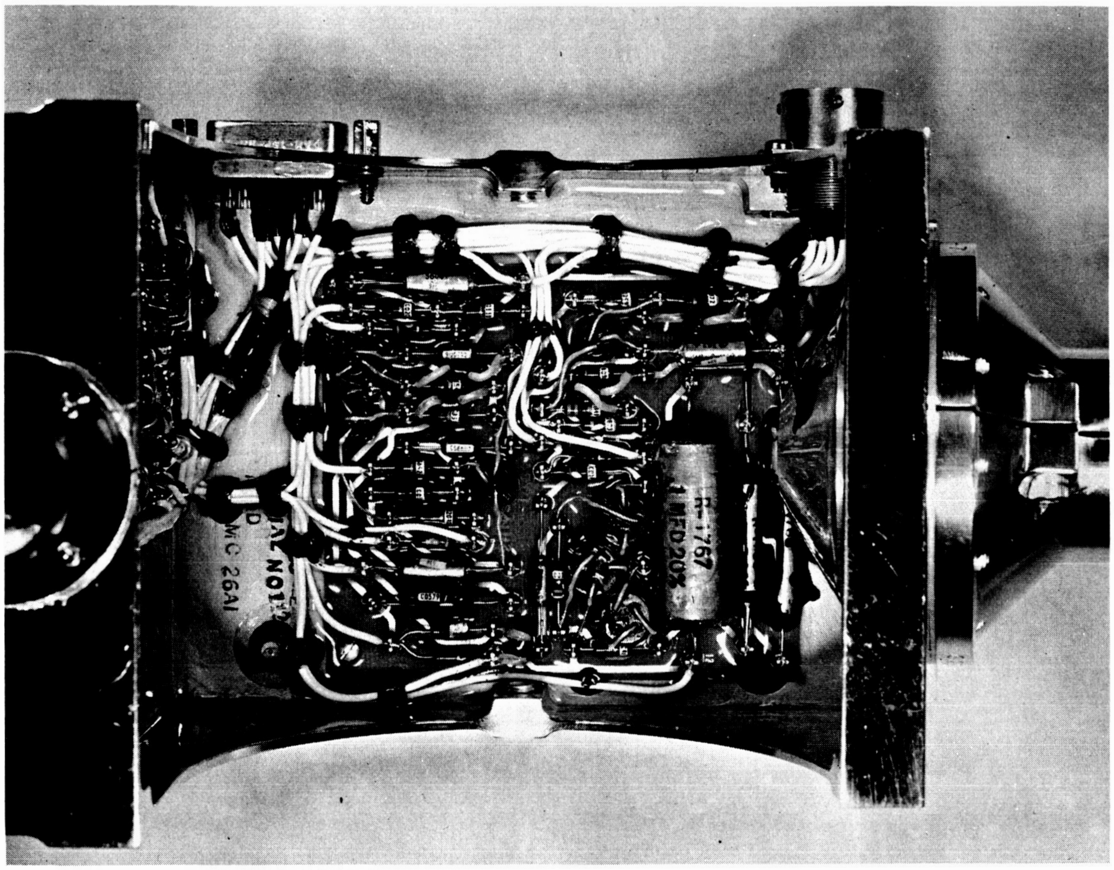


FIG. 3-4 CIRCUIT BOARD 2

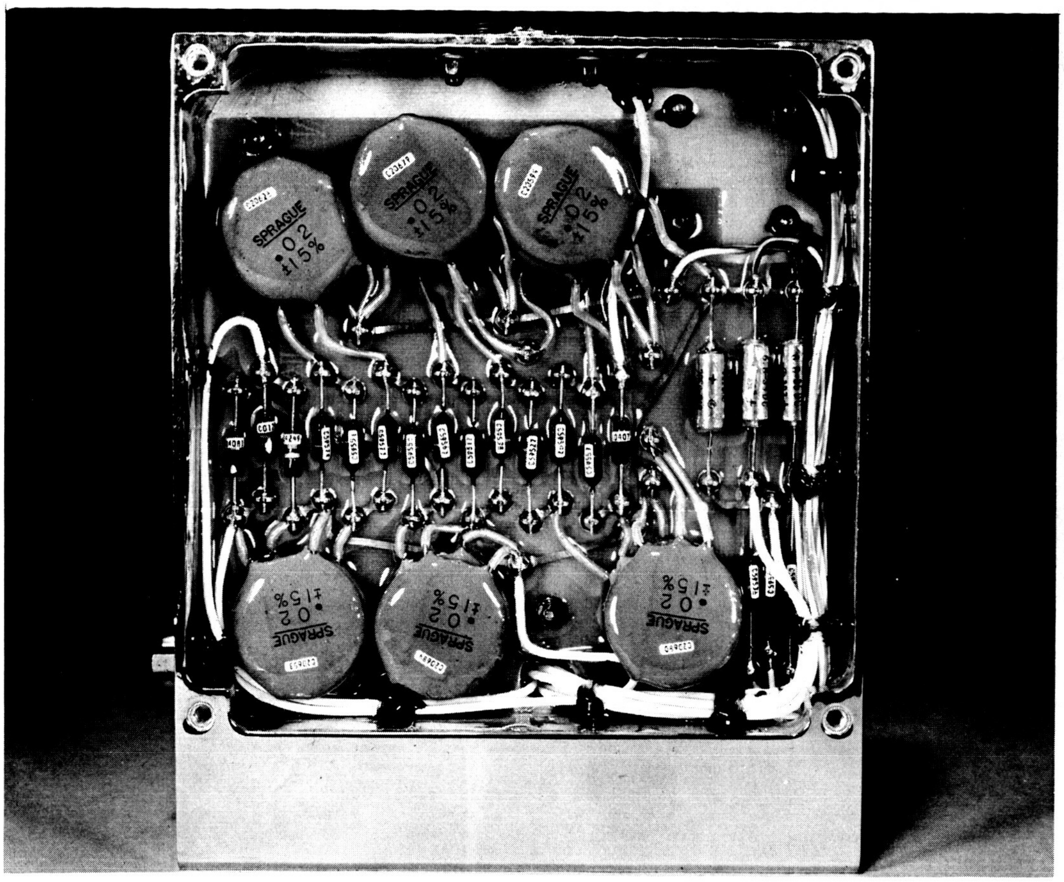


FIG. 3-5 CIRCUIT BOARD 3

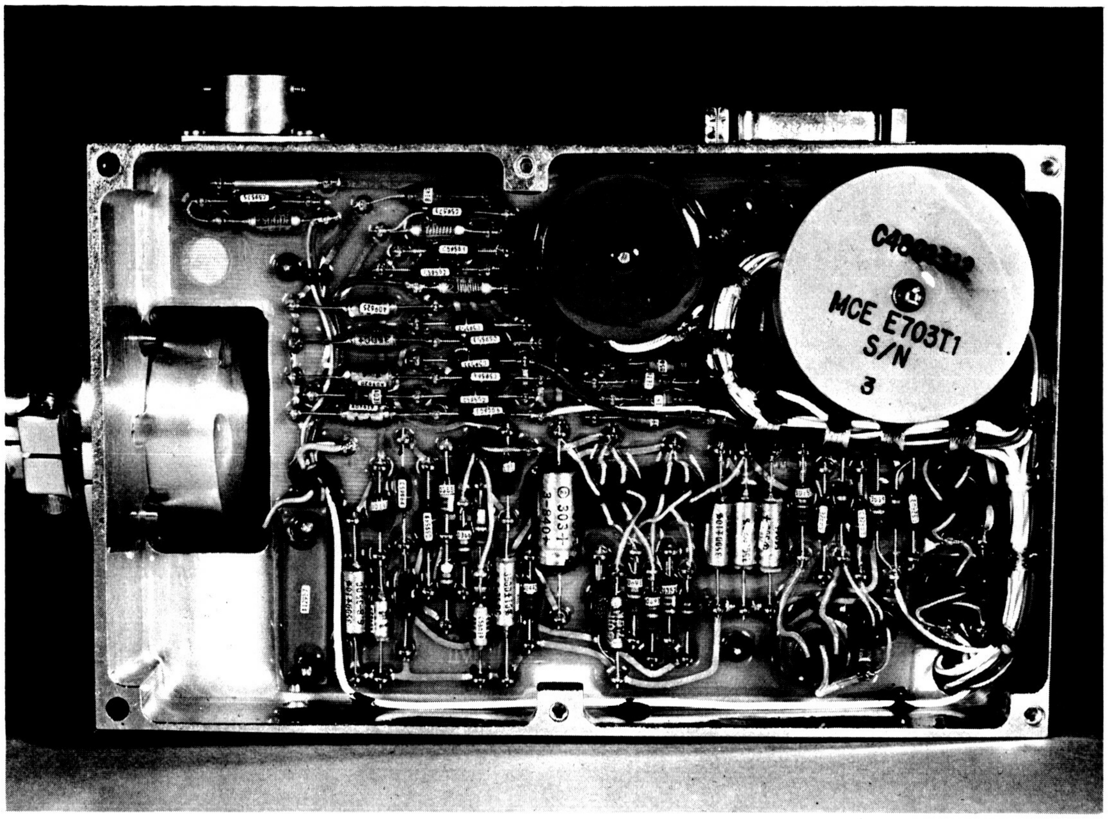


FIG. 3-6 CIRCUIT BOARD 4

3.4 Instrument Schematic

The ion chamber-Geiger tube instrument schematic is shown in Fig. 3-7. The various input and output signals are identified for connectors J1 and J2. Pins on connector J1 are identified by letters, and pins on connector J2 are identified by numbers. A transducer, MT1, for monitoring the temperature of the instrument during flight is connected between J1-13 and J1-14. The transducer is located to the left-hand side of Circuit Board 1, as shown in Fig. 1-1.

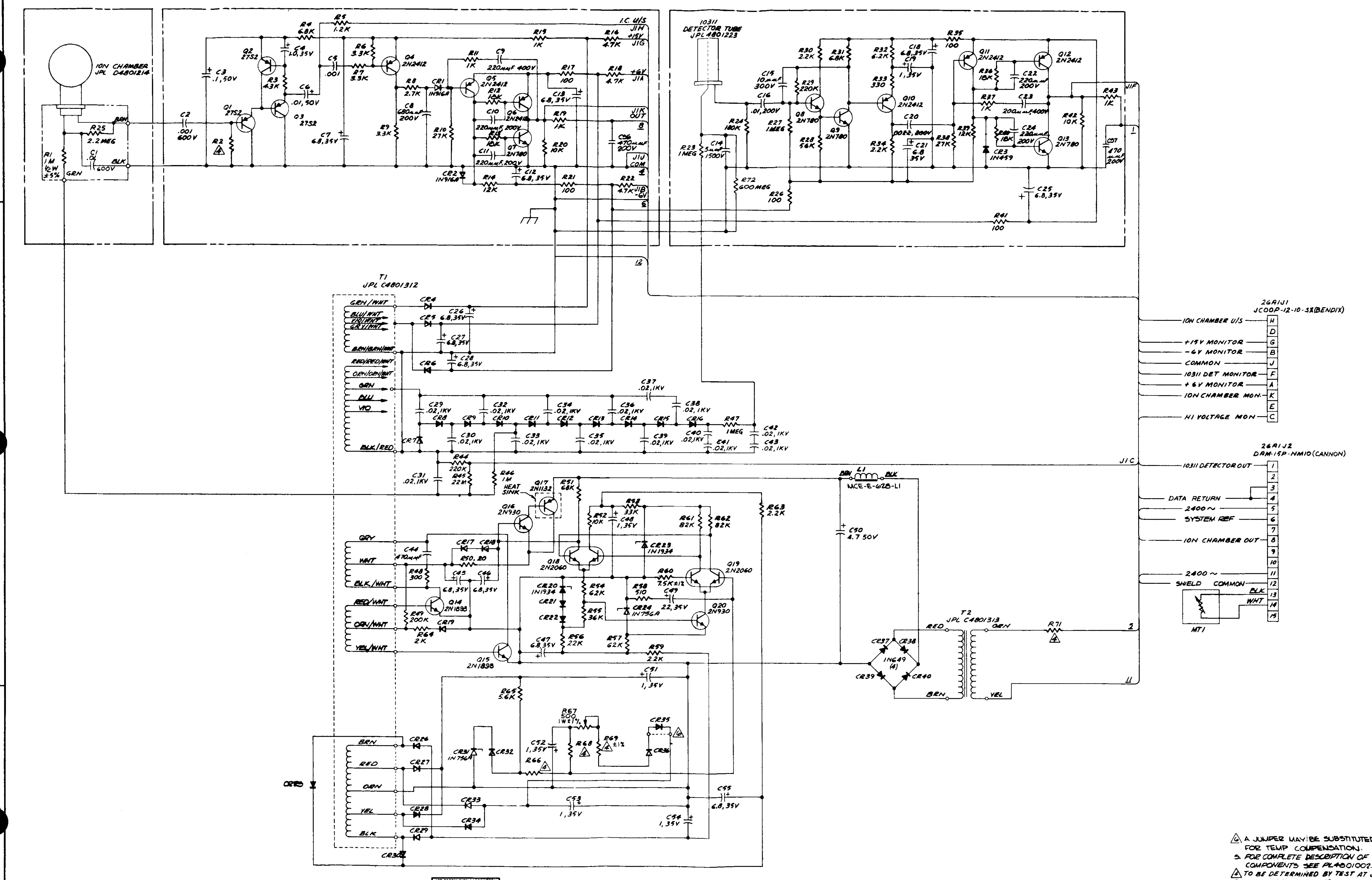
The ion chamber output signal is amplified and pulse shaped by the boxed circuit in the upper left-hand corner of Fig. 3-7. The G-M tube output signal is amplified and pulsed shaped by the boxed circuit in the upper right-hand corner of the schematic.

The power supply consists of all the components shown below the two boxed circuits. The low and high voltage dc power supply is below the amplifier and pulse shaping circuits. This power supply provides low dc voltage (-6, +6, and +15 vdc) to the amplifiers and pulse shapers, and high dc voltage for the ion chamber collector (310 vdc) and the Geiger tube anode (900 vdc). The ac input power is obtained from an inverter circuit (Q14, Q15, and the middle winding of T1). The dc input to the inverter is obtained from the regulator circuit (Q16 through Q20). The regulator input is obtained from the full-wave bridge rectifier (T2), which rectifies a 2400 cps input from the spacecraft power subsystem. The full-wave rectifier associated with the bottom T1 winding, provides regulated dc voltage for the regulator differential amplifier (Q18 and Q19).

3.5 Performance Characteristics

The performance characteristics of the ion chamber-Geiger tube instrument are summarized in Table 3-IV. These characteristics include types of radiations and their threshold levels, count rates, sensitivity, directional characteristics, accuracy, and output waveform characteristics.

REV	ZONE	CHANGE DESCRIPTION
A	3/4	A1) ADDED POLARITY TO CAP; A2) ADDED
A	6	DESIGNATIONS & VALUES TO C1, R1 & R25
A	1	A3) REMOVED R1, R25 & C1 FROM "REF
A	3	DESIGNATIONS NOT USED"; A4) AT J2-4
A	2	WAS "COMMON"; A5) NOTE 2 WAS MICRO
A	5	MICRO FARADS; A6) R67 WAS 300Ω;
A	5	A7) C8 WAS 400V; A8) ADDED 6, 12 CONN.
A	4	A9) C50 WAS 6.8, 35V A10) REVERSED
A	3	POLARITY OF C21 & C25
B	5	B1) R56 WAS 27K B2) R57 WAS 27K B3) R64
B	5	WAS 6.8K B4) ADDED RED/RED/WHT, ORN/
B	5	ORN/WHT WINDING TO T1
C		GENERAL REVISION
D	4	D1) ADDED R72



LAST COMPONENT REF DESIGNATION USED

RESISTOR	R72
CAPACITOR	C57
DIODE	CR40
TRANSISTOR	Q20
TRANSFORMER	T2
INDUCTOR	L1
CONNECTOR	J2
TRANSDUCER	MT1

REF DESIGNATIONS NOT USED
C17
R70

NOTES: UNLESS OTHERWISE SPECIFIED
1 ALL RESISTOR VALUES ARE IN OHMS 1/4W ±5%
2 ALL CAPACITOR VALUES ARE IN MICROFARADS
3 ALL DIODES ARE IN3579
4 TO BE DETERMINED BY TEST AT JPL
5 FOR COMPLETE DESCRIPTION OF COMPONENTS SEE PL4801002.
6 A JUMPER MAY BE SUBSTITUTED AT TEST FOR TEMP COMPENSATION.

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

ION CHAMBER
UNIT 26
SCHEMATIC DIAGRAM

J 4801002

NEXT ASSY J4801180 USED ON M-C
CLASSIFICATION UNCLASS SCALE NONE SHEET 1 OF 1 REVISION D

6-J-4801002-D 32

TABLE 3-IV

PERFORMANCE AND PHYSICAL CHARACTERISTICS OF THE ION CHAMBER-GEIGER TUBE INSTRUMENT

Characteristic	Description
1. **Radiation Threshold:**	
Ion Chamber	Electrons: 0.5 Mev
	Protons: 10 Mev
	Alphas: 40 Mev
Geiger-Mueller Tube	Electrons: 0.5 Mev
	Protons: 10 Mev
	Alphas: 40 Mev
2. Maximum Count Rates	
Ion Chamber	100 Counts/sec
Geiger-Mueller tube	50,000 counts/sec
3. Flux Sensitivity	Radiation changes in excess of 2 percent can be detected
4. Directional Sensitivity	
Ion Chamber	Omnidirectional
G-M tube	Omnidirectional (geometric factor = 7 cm^2)
5. Count Rate Accuracy	$\leq \pm$ 0.5 percent
6. Output Waveform	
Ion Chamber	
Amplitude	3 vdc
Pulse width	5 to 40 μsec
Rise time	1 μsec
Geiger Tube	
Amplitude	3 vdc
Pulse width	5 to 40 μsec
Rise time	1 μsec
7. Permissible Loading Impedance	470 ohms
8. Leak Rate	$\leq 2 \times 10^{-8}$ cm^2/sec of standard helium
9. Functional Life	
Ion Chamber	$> 10 \times 10^8$ counts[a]
Geiger Tube	$> 10 \times 10^{10}$ counts

[a] Based on results of Dr. Neher's experiments (CIT)

TABLE 3-IV (continued)

	Characteristic	Description
10.	Operating Temperature Range	-30 to 70°C
11.	Storage Temperature	-50° to 80°C
12.	Power Requirement	$\leq$ 500 milliwatts
13.	Weight	$\approx$ 2.6 lbs
14.	Magnetic Field Intensity	< 5 gammas at 3 feet from any surface
15.	Overall Dimensions	13.4 by 9.8 by 5 inches

4. DESIGN AND FABRICATION PROGRAM

The Ion Chamber-Geiger Tube Instrument Fabrication Program involved the Jet Propulsion Laboratory (JPL), the California Institute of Technology (CIT), and Electro-Optical Systems, Inc. (EOS). Design and testing of the instrument were performed by JPL and CIT, and EOS fabricated three prototype and three flight units (MC-2, MC-3, and MC-4). Table 4-I provides a breakdown of the various tasks performed during the program.

TABLE 4-I

DESIGN, FABRICATION, AND TESTING TASKS PERFORMED DURING PROGRAM

JPL	CIT	EOS
Circuit design and layout	Coated collector rod and fiber	Fabricated Geiger tube shield and transportation and handling guard
Purchased and screened electrical components and Geiger-Mueller tube	Completed assembly of header, electrometer, and sphere	Fabricated ion chamber (except for CIT tasks)
Performed functional, environmental, and acceptance tests on completed instruments	Performed bake-out and gas-fill operations on sphere	Assembled printed circuit boards
		Assembled entire unit and delivered to JPL

4.1 Program Organization

The organization chart for the Ion Chamber-Geiger-Tube Instrument Fabrication Program is shown in Fig. 1-2. The key JPL and EOS project members are identified under each task shown in the chart.

4.2 JPL Requirements

All JPL requirements stated in JPL Specification MC S-31578-DTL were satisfied by EOS during the fabrication program. These included materials, processes, hardware, review meetings, documentation, performance and product characteristics, and workmanship requirements. A brief summary of the work performed to satisfy these requirements is given below.

Materials, Processes, and Hardware

Materials, processes, and hardware were selected in accordance with JPL Specifications 20002, 20014, 20026, 20060, 20501, 20502, and 30261.

Methods Review

Before fabricating the prototype instrument, JPL reviewed and evaluated EOS material selection, fabrication processes, and quality control procedures.

Prototype Review

Prototype instruments were inspected by JPL for conformance to materials and workmanship requirements.

Material Review Board

A material review board for evaluating rejected components was established by EOS in accordance with the requirements of JPL Specification 30274.

Failure Reports

A failure reporting system, using JPL furnished report forms, was established for documenting all failures beginning with electrical testing of functional prototype assemblies.

Documentation

Copies of the quality control flow plan, material review board actions, and test procedures were delivered to JPL with each unit. (No failure reports were required from EOS because instrument testing was not performed by EOS.)

Performance and Product Characteristics

Performance and product characteristic requirements satisfied during the program include: (1) a maximum leak rate of 2×10^{-8} cm^2/sec of helium; (2) instrument configuration conformance to JPL drawing J480 1180; (3) dimension conformance to JPL drawing J480 1180; (4) interchangeability of parts and subassemblies of the same series; (5) incorporation of a removable filling tube and Kovar-to-glass seals in the header[a]; and (6) proper finishing of instrument surface to survive the flight thermal environment.

Workmanship

The workmanship conformed to requirements given in JPL Specification 20016.

4.3 Design Tasks

Most of the instrument design and development work was completed at JPL or under a previous EOS program[b]. The Geiger-Mueller tube was designed and built by Radiation Counters Laboratories, Inc. However, seven components in the ion chamber subassembly were redesigned by EOS during this program. These components include the silver cup for holding the quartz collector rod, the spider for attaching the cup to the header, the spider spring for preventing collector rod resonance, the neck cover, the ion chamber support for attaching the chamber to the electronics subassembly chassis, the removable filler tube, and the header. These components are shown in Fig. 3-2.

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[a] Kovar-to-glass seals were provided by the Bendix Cerameterm header pins.

[b] Design and Development of an Ion Chamber-Range Follow-On, JPL Contract 950272, EOS Report No. 3060-Final, 26 October 1962

4.4 Fabrication Plan

The main tasks required to complete the program are identified in the JPL Flow Plan (PERT Chart) shown in Fig. 4-1. This plan identifies all EOS and CIT tasks and schedule data for the fabrication and testing of the ion chamber-Geiger tube instrument. The tasks performed by JPL before and after release of the purchase order to EOS are also shown in the plan.

4.5 Fabrication Techniques

The materials and techniques employed to fabricate the various components and subassemblies of the ion chamber-Geiger tube instrument are summarized in Table 4-II. The principal components or subassemblies covered in this table include the ion chamber, the G-M tube shield, the printed circuit boards, and the electronics subchassis. Fabrication techniques for components supplied by JPL or CIT are not included in the table.

4.6 Quality Assurance

A quality control program was established by EOS in accordance with the format outlined in JPL Specification 30274. As a result of this program a quality control plan[a] was completed and approved before flight hardware fabrication. The quality control plan included a flow chart covering all phases of assembly, test, and inspection from initial receipt of raw materials to delivery of completed units to JPL. Quality assurance procedures for this program are discussed below.

Inspection of Components

All purchased parts, components, and assemblies were subjected to receiving inspections, which included screening and testing when applicable. Procurement procedures ensured such inspections in all cases where components were to be used in end items. In-process inspections and tests were performed on all fabricated parts according to the production flow diagrams approved by JPL. Final

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[a]See appendix

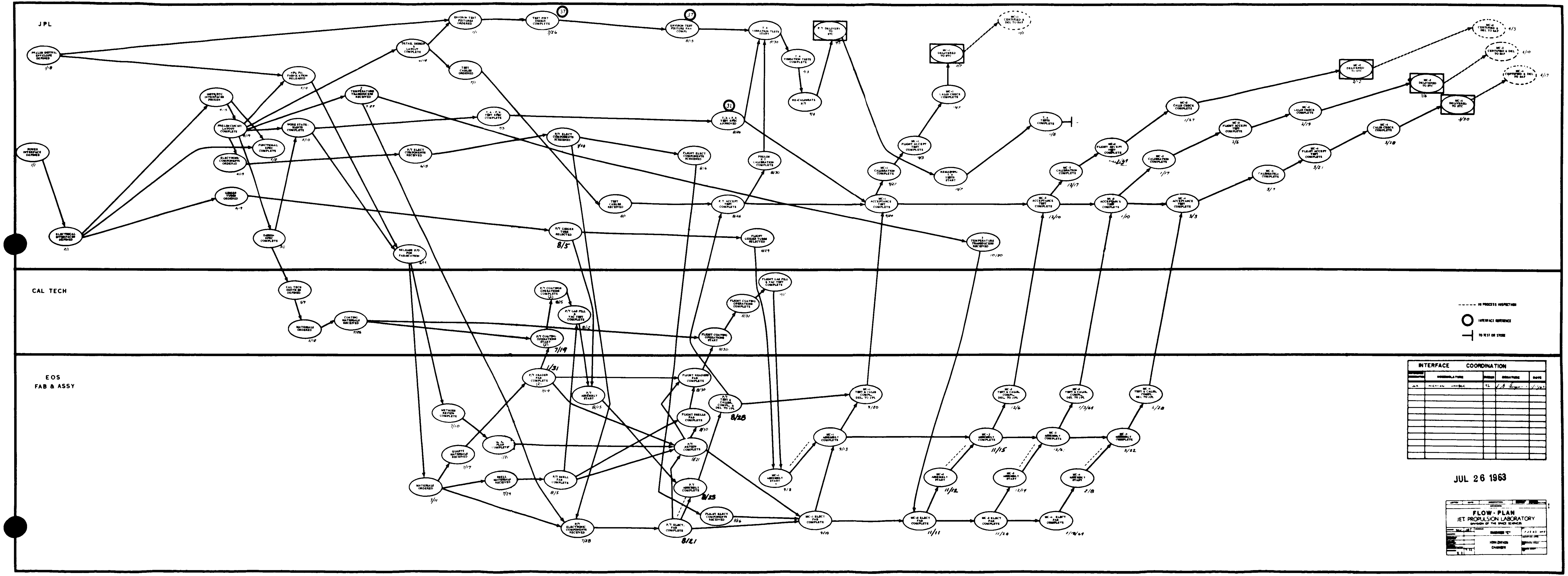

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FIG. 4-1 JPL FABRICATION FLOW PLAN

TABLE 4-II

INSTRUMENT FABRICATION TECHNIQUES[a]

Component/Subassembly	Material	Process
Sphere	Stainless steel	
Fabrication		Hydroforming, heli-arc welding, and chem-milling
Finish		Black oxide
Collector Rod	Fused quartz	Hand-drawn from solid quartz rod
Chamber Neck	Stainless steel	Machined
Chamber Support	Stainless steel	Machined
Spider	Beryllium copper	Machined
Collector Cup	Silver	Machined
Spider Spring	Elgiloy	Hand-formed and heat-treated
Header	Stainless steel base and Bendix Cerameterm pins (Kovar-to-glass)	
Fabrication		Machined and brazed
Finish		Silver-plated
Cover	Aluminum	
Fabrication		Stamped, hand-polished
Filler Tube	Copper tubing	Cut from stock
Header Fitting	Stainless steel	Tube and fitting brazed together
Geiger Tube Shield	Stainless steel	
Fabrication		Machined
Finish		Black oxide

[a]Fabrication techniques for components or subassemblies supplied by JPL or CIT are not included.

TABLE 4-II (continued)

Component/Subassembly	Material	Process
Printed Circuit Boards	Epoxy-laminated board	Hand-assembled and hand-soldered
	Gold-plated etched circuits	
Subchassis (electronics)	Forged magnesium (Mg)	
Fabrication		Machined from a solid block of Mg
Finish		Coated and polished with copper, nickel, and gold

inspection of each item produced was made in accordance with the EOS Quality Control Manual. Inspection marking techniques were approved by JPL. Quality Control program records were maintained in accordance with the EOS Quality Control Manual, and are available to JPL upon request.

Material Control Flow - Material control began upon initiation of procurement. The note "Production Procurement" on the purchase request indicated that a part would be selected from either the preferred parts list or the approved vendors list, as applicable. A certificate for each item ensured that the components were subjected to receiving inspection prior to acceptance by EOS. Acceptable components were stored in the stock room until needed for fabrication.

Electronic Components - All electronic components were identified by an appropriate code that was retained throughout inspection, test, and final disposition of the parts. A complete history of each part was recorded and kept on file. Recorded data included test measurement values, a description of the test performed, and the final disposition of the part. Parts screening tests were performed in accordance with JPL Test Specification No. 30237A, Screening Inspection for Electronic Parts.

Documentation - Within the assembly activity, in-process goods were identified at all times with attached travellers that contained assembly, test, and inspection status information. The sequence of fabrication, test, and inspection actions were set forth in production flow diagrams devised for the particular electronic assembly involved.

Periodic Calibration of Testing and Measuring Equipment

As a part of the product assurance plan prepared during initial project planning, the project supervisor issued a list of measuring and testing equipment that required periodic calibration for the project.

Time and Period of Calibration

All instruments on the list were calibrated before initiating construction of prototype and flight hardware. The project supervisor scheduled the work flow to minimize disruption of work during instrument calibration.

The interval of calibration was adjusted for the stability, usage, and purpose of the equipment. Typical calibration intervals were a 3-month period for electronic equipment and a 6-month period for mechanical equipment. However, equipment was calibrated after any event that may have affected its accuracy. If a calibration interval was not specified by the project supervisor or coordinator, a Quality Assurance representative assigned an interval.

Duties of Quality Assurance - The Quality Assurance Department was responsible for assuring that proper calibrations were performed on equipment designated above. A department purchase request was prepared for the calibration of each instrument. Other forms were prepared to initiate action at the re-occurrence of the calibration interval. To facilitate scheduling, the Quality Assurance Department notified the project supervisor 2 weeks in advance of the calibration period. When required by the project supervisor, the instrument was calibrated in advance of its normal schedule.

The Quality Assurance Department maintained a file on all regularly calibrated instruments, by project work authorization, until the termination of the project. The department also provided calibration status identification for the project's testing and measuring equipment.

Drawing and Specification Control

Drawing and specification control was established and maintained by the project document control center and was monitored by the Quality Assurance Department for availability, distribution, and accuracy.

Major Subcontractor Control

In cases of procurement of major fabrication services or goods, EOS assumed responsibility for subcontractor compliance with JPL quality assurance provisions. This was accomplished by proper subcontract arrangements, by source inspections by EOS Product Assurance personnel, and by supervision of subcontractor performance by the EOS liaison engineer.

4.7 Documentation and Engineering Data

Technical and financial progress for this program was reported on a monthly basis. Informal letter-type reports included brief summaries of all major developments during the previous month. Financial data were presented graphically and included actual and projected monthly expenditures, total funds expended to date, and original contract funds estimated for completion of the program.

Other documents supplied to JPL during the contract period, included failure and inspection reports, a materials list, and a quality control plan. A complete set of reproducible detail drawings on the instrument was delivered to the customer.

4.8 Problem Areas

No major technical or fiscal problems developed during the Ionization Chamber-Geiger Tube Instrument Program. However, several minor design and fabrication problems arose and are presented below.

Engineering Drawings

Early in the design phase of the program, it was discovered that engineering drawings used for producing earlier models of the ion chamber did not include the changes required for the Mariner C instrument. Therefore, it was necessary to prepare a complete set of new drawings. Minor drawing changes were made to several. However, new drawings were required for the chamber spider, spider spring, header base, tube fitting, and circuit boards. It was necessary to prepare drawings for the ionization chamber support and a composite drawing of the entire instrument, including the ion chamber, G-M tube, and electronics chassis - the latter drawing being necessary to procure shipping containers. These drawing changes posed no major technical problems; however, time consumed for this task exceeded the amount originally anticipated to complete new drawings.

New Header Design

The new header configuration was satisfactory with only two minor problems. The first unit utilized a collector cup that was soldered to the spider. During the soldering operation, the spider spring became annealed and provided no damping during vibration. The redesigned unit used a truarc snap ring as a fastener and no soldering was necessary. During vibration, the cup rotated in the spider. Since the wire (Fig. 3-2) connecting the side arm to the header could break if the cup rotated too much, it was necessary to prevent this movement. Several methods were tried, with only token success. However, the final method was to silver solder a steel pin to the cup and notch the spider to accept the pin. This method was satisfactory and did not affect the vibration characteristics of the electrometer.

Electronics Subchassis

Another problem occurred in the fabrication of the electronics subchassis. Procurement problems resulted from processing changes on released drawings that were not specified in the preliminary drawings used for EOS cost estimates. Since only one source was available, several weeks were required to obtain the subchassis material. There were also problems involved in placing a subcontract for machining this part, and several vendors refused to bid. The order was finally placed and the prototype and flight units received at EOS were satisfactory. The material used in the first two units was borrowed from JPL and replaced after EOS received the material from its vendor. JPL also furnished special Kaynar inserts for the subchassis because long lead-time and large minimum order requirements would have delayed the program.

Electronic Fabrication

The remaining problems occurred during electronics fabrication. The first problem was that insufficient components were received from JPL to commence assembly. Upon receipt of the components, a receiving inspection was performed and many of the more critical components were rejected for nicked leads, pits and voids in solder seals, and damaged surfaces. The rejected components were returned for JPL disposition. The remaining usable components were coated with Eccoseal, and the assembly progressed as far as possible with the available components. The time consumed by inspecting and rejecting components resulted in a severe tightening of the schedule.

Black Oxide Coating

Another problem area involved the black oxide coating used for thermal control on the sphere. Several operations were performed after the coating was applied. After these operations were completed, an effort was made to clean the coated surface with water. This resulted in streaking and removal of a portion of the coating. Upon investigation, it was discovered that black oxide coatings are very difficult to clean and should only be attempted when absolutely necessary. The vendor who performed this operation recommended the use of trichlorethylene as the only solvent for cleaning the oxide coating.

Header Pin Leakage

The next problem was with header pin leakage. Several headers developed small leaks during temperature cycling. After replacement of the faulty pins, the headers were again cycled without developing any leaks and accepted. The reason for this problem was not determined.

Sphere Leakage

Ionization chamber sphere leakage was another problem. Six of seven spheres had leaky weld joints. Several of the spheres were returned twice to the vendor for rework. This problem was evidently due to a change in material from 321 stainless steel to 347 stainless. Prior to this material change, 30 to 50 spheres were made using 321 stainless steel, with absolutely no leaky weld joints. It is recommended that the use of 347 stainless be discontinued on future programs.

Spider Spring

A major problem developed in the ionization chamber construction which delayed delivery of the prototype model. After bake-out the chamber was placed on a vibration table at JPL. During vibration a rattling sound was emitted from the chamber. The unit was removed from the table and disassembled. Upon examination, it was found that the spider spring was loose and no longer provided tension for holding the cup to the header. The electrometer was returned to EOS for further examination of the header which revealed that the unit was subjected to a temperature in excess of 572°F during bake-out. The spider spring was constructed from beryllium copper, which has an annealing point of approximately 1400°F, and should, therefore, not be affected by bake-out at 572°F (300°C). Further investigation revealed that although the beryllium copper was annealed at 1400°F, it begins to soften at 600° to 650°F. Thus, the 4-hour bake-out at a temperature greater than 572°F was sufficient to cause the small change in shape that took place in the spider spring and the reduced tension on the collector cup.

Use of a different material for the spider spring solved the problem. From several possibilities, a material known as Elgiloy was selected. This material is capable of withstanding temperatures up to 950°C and was, therefore, suitable for this application. After some difficulty in securing Elgiloy in the proper state to allow forming, two spider springs were fabricated and heat-treated. The two springs were then incorporated in header subassemblies and performed satisfactorily after bake-out. Elgiloy springs were used in all ionization chambers delivered to JPL.

Pre-Mixed Frozen Solithane

Pre-mixed frozen solithane was used to conformal coat the printed circuit boards. However, JPL informed EOS that several contaminated samples of the pre-mixed solithane were found. Therefore, EOS discontinued its use and mixed the solithane in the laboratory before coating the circuit boards.

Geiger-Mueller Shield

One Geiger-Mueller tube shield (Fig. 3-3) was separated from its end cap during environmental temperature testing. To prevent future occurrences of this problem the RTV insulators were shortened to reduce internal pressure on the cap after assembly. The problem did not re-occur after this change was made.

Printed Circuit Board

Some difficulty was experienced with crazing around the terminals of printed circuit boards. Since there were no existing criteria for determining acceptability of the boards, the following standard was used: the board was rejected when crazing exceeded twice the terminal diameter on adjacent terminals not connected by printed circuitry.

5. CONCLUSIONS

Three prototype and three flight ion chamber-Geiger tube instruments were fabricated to JPL specifications. These instruments satisfied all workmanship, performance, and environmental requirements. Flight instruments were subjected to vibration and shock tests at JPL. Since life tests were not part of this program, achievement of the goal for fabricating an instrument that will continuously operate for 400 days in a space environment could not be verified. Further testing is necessary to determine life expectancy.

Design achievements include replacement of the previously used header pins with Bendix Cerameterm pins, redesign of the collector mounting cup and spider, and modification of the header base to accommodate a removable chamber filler tube. The method of mounting the ion chamber to the electronics chassis was modified to isolate the header pressure seal from stresses due to vibration. Thus, the probability of Argon leakage from within the sphere was reduced.

Although no major design or fabrication problem arose during the program, several minor problems were resolved by the staff at EOS. These problems included header pin leakage, sphere weld joint leakage, circuit board terminal crazing, and spider spring tension failure. These problems were solved without great difficulties and did not significantly increase the cost of the program.

Several component design improvements for increasing the instrument's reliability and reducing its cost were developed during this program. These improvements are briefly discussed below and are recommended for incorporation into all future ionization chamber-Geiger tube instruments. (All recommendations refer to the ionization chamber subassembly.)

Header Pins

New methods for attaching Cerameterm pins to the header base of the chamber should be investigated. The current method involves brazing the pins to the header individually. This process is time consuming (several hours per header), results in non-uniform solder joints, and requires careful cleaning of the subassembly after brazing. An oven brazing process, using pins with pre-formed solder, will eliminate these disadvantages and will reduce the probability of developing header leaks. Since oven brazing has not been tested, additional development is required to evaluate and perfect this method.

The header contains two spare Cerameterm pins. These pins perform no useful function and reduce ion chamber reliability because they increase the number of potential leak sources for the gas in the sphere. Lower cost is an additional advantage of eliminating these pins, since fewer Cerameterm pins would be brazed to the header.

Shielding Can

Future ion chamber shielding cans should be made with stainless steel instead of copper. If stainless steel is used, the shield can be hand-formed instead of electroformed, and the cost of fabricating this component will be reduced by $75 per unit.

Spider

The spider is made of beryllium copper. This material softens, changes shape, and loses some of its elasticity at the chamber bake-out temperature ($300^{\circ}C$). This change in the beryllium copper structure reduces the tension force on the collector cup and can result in a loose collector rod. Although no cups and rods became loose during this program (see Section 4.8), future units may be critically affected since a loose rod would break during vibration testing. To avoid this possibility, the spider should be fabricated out of stainless steel to retain its elastic properties when subjected to temperatures in excess of $300^{\circ}C$.

The spider contains two holes that serve no function. Elimination of the holes will reduce the cost of fabricating this part and will increase its strength.

Interchangeable Collector and Header

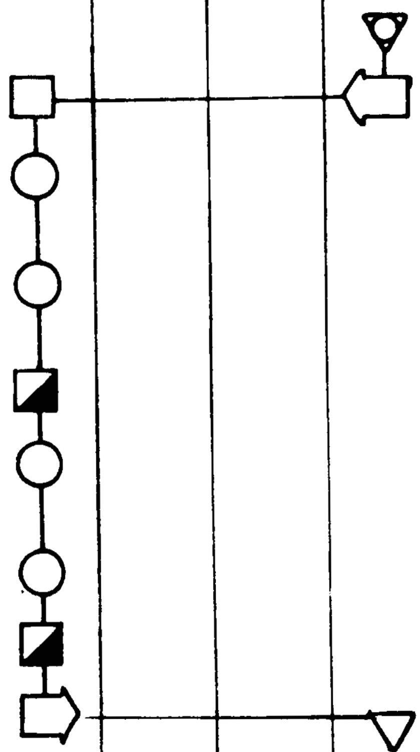
Occasionally an electrometer subassembly must be discarded when a header leaks or a collector rod is damaged during handling. A portion of this subassembly can be salvaged when the header and collector can be interchanged with other collectors and headers. Component interchangeability can be obtained by manufacturing the spider to closer tolerances. Although closer tolerances will increase the cost of the individual components, the overall cost will be lower because fewer electrometer subassemblies will be rejected.

APPENDIX

QUALITY CONTROL FLOW PLAN
(PRODUCTION FLOW CHART)
FOR
IONIZATION CHAMBER-GEIGER TUBE
INSTRUMENT FABRICATION PROGRAM

CB1

OPER. NO.	OPERATION DESCRIPTION	ELEC ASSY	EL-TRO MECH	TEST	STORE	SPECIFICATIONS EOS	SPECIFICATIONS JPL
	4801303					EOS	JPL
10	Kit of Parts						
15	Inspection					2000	
20	Clean & Bond Transistors to Board						20060
30	Clean & Bond Insul. Board to Term. Bd.						20060
35	Inspection					2001	
40	Install Components Clean						20026 20016
50	Identify & Coat						20002
55	Inspection					2003	
60	Storage - Hold for Final Assy. 4801180						



PROGRAM Mariner C

DATE September 13, 1963

OPER. NO.	OPERATION DESCRIPTION	ELEC ASSY	EL-TRO MECH	TEST	STORE	SPECIFICATIONS EOS	SPECIFICATIONS JPL
	4-01180						
10	Kit of Parts						
15	Inspection					2000	
20	Identify & Coat						20002
30	Bond Circuit Boards to Chassis & T1 to CB4						20060
40	Bond Q17 into heatsink Loc-Tite terminal						20060
45	Inspection					2006	
50	Install Chassis Mounted Components						
60	Mount J1 & J2 (Torque)						90314
65	Inspection					2007	
70	Interwire - Install MT1						20016
[redacted]	[redacted]					[redacted]	
80	Install Tube & Chamber						20016
85	Inspection					2007	
90	Test						
95	Inspection					2007	
100	Spot Bond & Conformal Coat						20060
105	Inspection					2006	
110	Install Cover						20016
115	Inspection					2009	
120	Staging						

RELEASE DATE OF DRAWING	
DWN	ENGR
CHK	DES CHIEF
MATL PROC	P.L.

PRODUCTION FLOW CHART 26A1

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

CROSS REFERENCE

CLASSIFICATION | SCALE | DWG SIZE | SHEET OF | REVISION

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CB2

OPER. NO.	OPERATION DESCRIPTION	ELEC ASSY	EL-TRO MECH	TEST	STORE	SPECIFICATIONS	
	4801305					EOS	JPL
10	Kit of Parts						
15	Inspection					2000	
20	Clean & Bond Transistors to Board						20060
30	Clean & Bond Insul. Board to Term. Board						20060
35	Inspection					2001	
40	Install Components Clean						20026, 20016
50	Identify & Coat						20002
55	Inspection					2003	
60	Storage - Hold for Final Assy. 4801180						
	4801180-901					EOS	JPL
10	Kit of Parts						
15	Inspection					2000	
20	Wire J2 - Clean						20014
25	Inspection					2004	
30	Sleeve Pins						20016
35	Inspection					2005	
40	Storage - Hold for Final Assy. 4801180						

CB3

OPER. NO.	OPERATION DESCRIPTION	ELEC ASSY	EL-TRO MECH	TEST	STORE	SPECIFICATIONS	
	4801307					EOS	JPL
10	Kit of Parts						
15	Inspection					2000	
20	Clean, Locate & Bond Insul. Board & Capacitors to Term. Bd.						20060
25	Inspection					2001	
30	Install Components Clean						20026 20016
40	Identify & Coat						20002
45	Inspection					2003	
50	Storage - Hold for Final Assy. 4801180						
	4801180-900					EOS	JPL
10	Kit of Parts						
15	Inspection					2000	
20	Wire J1 - Clean						20014
25	Inspection					2004	
30	Sleeve Pins						20016
35	Inspection					2005	
40	Storage - Hold for Final Assy. 4801180						

PART NAME Ion Chamber

PART NUMBER 4801180

CB4

OPER. NO.	OPERATION DESCRIPTION	ELEC ASSY	EL-TRO MECH	TEST	STORE	SPECIFICATIONS EOS	SPECIFICATIONS JPL
	4801309					EOS	JPL
10	Kit of Parts						
15	Inspection					2000	
20	Clean & Bond R70 & Transistors to Board						20060
30	Clean & Bond Insul. Board to Term. Board						20060
40	Clean & Bond L1, T2 & R67 to Term Bd						20060
45	Inspection					2001 2002	
50	Install Components Clean						20026 20016
60	Identify & Coat						20002
65	Inspection					2003	
70	Storage - Hold for Final Assy. 4801180						

LEGEND:

- Operation
- Inspection
- JPL Inspection
- Transportation
- Storage